Low Cost Wireless Sensor Network for Structural Health Monitoring

Chougule, Prasad; Kirkegaard, Poul Henning; Nielsen, Søren R.K.

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Chougule, P., Kirkegaard, P. H., & Nielsen, S. R. K. (2010). *Low Cost Wireless Sensor Network for Structural Health Monitoring*. Paper presented at Scandinavian Vibration Forum : Skandanaviska Vibrationsforenigen (SVIB), Linkoping, Sweden.

Low Cost Wireless Sensor Network for Structural Health Monitoring

P.D. Chougule*,[a], P.H. Kirkegaard[a], S.R.K. Nielsen[a]

[a]*Department of Civil Engineering, Aalborg University, 9000 Aalborg, Denmark*

Abstract

To ensure the long life operation of wind turbines critical structural elements such as the blades have to be controlled continuously for fatigue damage and other types of failure modes by means of a Structural Health Monitoring (SHM) system. From an economical and a maintenance point of view, the traditional wired SHM systems have limitations when used in e.g. wind turbine applications. Hence low cost Wireless Sensor Network (WSN) in a SHM system is proposed in this work. An available commercial wireless sensor setup for a SHM is expensive; hence there is need of cheap wireless sensor setup. In order to investigate the functionality of a low cost WSN, two cheap wireless accelerometers (less than $50 each) with micro-controllers are tested in a cantilevered beam laboratory test setup time-series data is measured. Spectral analysis using Fast Fourier Transform (FFT) is carried out for measured data at each micro-controller and only frequencies are transferred to a host computer to reduce the power requirement in data transmission. In this work performance of the WSN is investigated with reference to the data interrogation.

Key words: Wireless Sensor Network, SHM, Data Interrogation.

1. Introduction

Recent trend in the wind energy sector is the development of large wind turbines for offshore installation. The maintenance of such structures is a critical issue because of accessibility. Hence the online structural monitoring of wind turbine system has gotten importance in the last decade. The aim of the SHM system is to detect, locate, categorize and quantify the damage. Further the remaining time of failure in the structure is determined to avoid catastrophic failure of the structure [1]. An overview of the definitions, the terminologies and the categorization of the structural health monitoring system (SHM) is given in literature [3]. A damage detection method depends on the level of intelligence required in a SHM system. A review of damage detection methods can be found in the literature [1]. It can be seen from the literature that, disputes the different damage detection methods, each of them has sensor as a common element. In such damage detection method an array of sensors is used to detect the damages. A traditional wired sensor network is not suitable for a wind turbine application, because of accessibility. An alternative to the wired sensor network is a WSN which has many advantages. But the WSN does have limitation which needs to be solved. Two well know problems are its power source lifetime and reliable data transmission range [4].

The ongoing developments of a WSN have focus on design of a network which is low cost and power efficient. Wireless sensors are battery operated modules and used for long life operation. To ensure the long life of the wireless module it should be designed for less power consumption. Such a low power consumption wireless module consists of an embedded damage detection algorithm for operational power efficiency, which is proposed in literature [4]. The intended purpose of the embedded computational core at the sensor is to permit the engineering analysis by sensors because it needs less power for computation than the data transmission. Decentralization of computational core permits benefits like, it reduces the size of data to be transferred and hence less power consumption in data transmission.Dual architectural micro-controllers are used for SHM to increase the power efficiency. The low bit micro-controller is good for an overall operation whereas high bit micro-controller is good for execution of expensive embedded engineering data analysis. Such micro-controllers have been implemented in a

*Corresponding author, Tel: +45 9940 8583, Fax: +45 9814 8243
Email addresses: pdc@civil.aau.dk (P.D. Chougule), phk@civil.aau.dk (P.H. Kirkegaard), srkn@civil.aau.dk (S.R.K. Nielsen)

many commercially available wireless modules. These modules with damage detection software are expensive, but the micro-controllers used in the modules are cheap. In the present project a low cost micro-controller with a sensor is used for data interrogation and the same unit consists of a wireless module for data transmission. Details of the hardware used are given and the limitations over range of data transmission will be discussed. Further a functionality of the WSN will be investigated related to an experimental study of a cantilevered beam mounted with two accelerometer. The Accelerometers are equipped with an Arduino micro-controller with a wireless module for data transmission. The idea is to process the time series data at the remote wireless module to reduce the amount of data to be transmitted to the computer for further analysis.

2. Wireless Sensor Network Elements

By keeping in mind the reasonable fabrication efforts and low cost of wireless sensing unit, a modular design of wireless sensor unit is selected for ongoing project. A fundamental building block of any wireless sensor network is the wireless sensor.Any wireless sensors have functional subsystems as shown in figure 1.

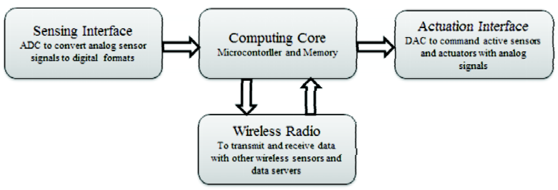

Figure 1: Functional Subsystems of Wireless Sensors

Sensing Interface converts an analog input signal to digital formats. The quality of sensor interface is defined by a function of the conversion resolution (16 bits or higher), sample rate (e.g. less than 500 Hz), and number of channels available on its analog-to-digital (ADC) convertor [2]. When data is measured by sensing interface, the computational core takes care of data for processing, storage, and readied for communication. Computational core is represented by a micro-controller that can store measurement data in random access memory (RAM) and data interrogation in programs in read only memory (ROM). The speed of computation for micro-controller is defined by the size (in bits) of micro-controller. It is known that if speed of micro-controller increases, there is a linear increase in power consumption. Hence the size of micro-controller is decided by the amount of data interrogation to be performed by a micro-controller. To connect with other sensors and to transfer data to central unit, a Trans-receiver is necessary. These are called as radios, specified by the frequency and a range of data transmission. These Trans-receivers are also called as radio frequency modules. A summary of academic wireless sensing unit prototypes and commercial wireless sensing unit prototypes is given in the literature [2].

As discussed above we have selected low cost ($25) Arduino Duemilanove Board with ATmega328P-PU Micro-controller [6][7]. Arduino Duemilanove board has 14 digital input/output pins, 6 analog inputs, a 16MHz crystal oscillator, a USB connection, a power jack, an ICSP header and a reset button.It has battery power option to get started which makes it usable for wireless technique. ATmega328P-PU is a 8-bit core, 20MHz, 32KB flash memory, 2KB SRAM microprocessor. The Arduino Duemilanove automatically selects the appropriate power supply (USB or external power), eliminating the need for the power selection jumper. It also adds an easiest to cut trace for disabling the auto-reset, along with a solder jumper for re-enabling it.

An XBee-PRO 802.15.4 (series 1) OEM RF module [8] is used for a wireless data transmission to satisfy the low cost, low power WSN. The XBee-PRO 802.15.4 module operates within the ISM 2.4 GHz frequency band. It has 100 mW EIRP power output (up to 1500m outdoor range), U.FL RF Connector, RPSMA, Integrated Whip antenna, 250 Kbps data transfer rate. It supports Point to Point, Point to Multipoint, Peer to Peer network technologies. MaxStream RF modems are easy to configure offline using X-CTU software [9]. To connect this RF module on Arduino Duemilanove Board it needs an XBee Wireless Shield [10]. It helps to supply 3.3 VDC to XBee modem by taking power from the 5V pin of the Arduino. The shield also takes care of level shifting on the DIN pin of the XBee. It has indicator LEDs as like Arduino Duemilanove Board. Figure 3 shows the assembly of XBee modem, Shield and Arduino Duemilanove Board.

A three axis 1.5g micro machined accelerometer $2 is used to measure the accelerations of the cantilever beam [11]. This accelerometer provides a sleep mode which is important in case of battery operated products. It typically consumes 400 microA of current. Fig 2 shows the MMA7361L accelerometer. It has bandwidth response of 300 Hz in z direction and sensitivity of 800mV/g for 1.5g. Selection of this accelerometer is done based on

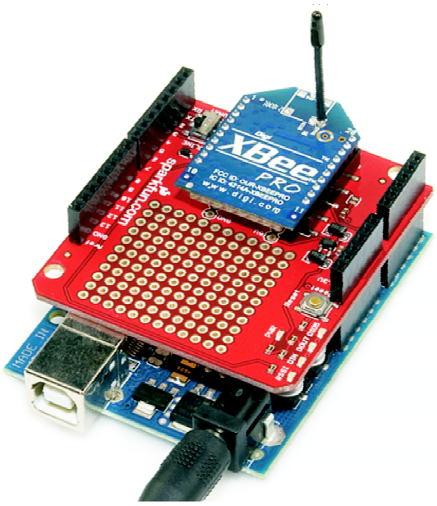

Figure 2: Arduino mounted with XBee RF and XBee Shield

its applicability to the laboratory test setup. This accelerometer may not be useful for wind turbine applications, but there are other sensors like piezoceramic actuators which are mainly used in damage detection techniques.

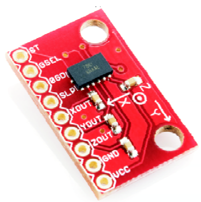

Figure 3: Accelerometer

3. Laboratory Test Setup

To implement network of the wireless sensor unit a cantilever beam is designed as shown in figure 4. Two wireless unit work as a remote modules and mounted on the cantilever beam. One wireless unit is connected to the computer to collect the data from remote modules. RF1 and RF2 denote the Radio Frequency Module 1 and 2 respectively. RF2 module is mounted at the center of the cantilever beam.

An Accelerometer mounted at the end of cantilevered beam reads the acceleration values and send to the micro-controller. A micro-controller has an algorithm

Figure 4: Laboratory Test Setup

to process Fast Fourier Transform (FFT) for sampled data in Random Access Memory (RAM).To form a network another wireless module is mounted at the mid length of a cantilever beam. It is aimed in this work to establish a peer to peer communication between these two wireless modules. By establishing a communication between two wireless modules it will be easy to find out the state of the system at the particular location and to investigate power consumption during data interrogation and data transmission. In commercially available wireless sensor units it is easy to establish a communication between two wireless modules because of embedded software which makes this costly. Whereas low cost wireless sensor unit an algorithm which takes care of data interrogation have to be developed. To design such an algorithm hardware in the system plays important role. Selection of suitable hardware is carried out keeping in mind low cost and applicability to the laboratory test setup.

By exciting the cantilever beam accelerometer data at (RF1) is collected through X-CTU software. Figure 5 shows the Fast Fourier Transform for the time series data obtained from the wireless sensor.

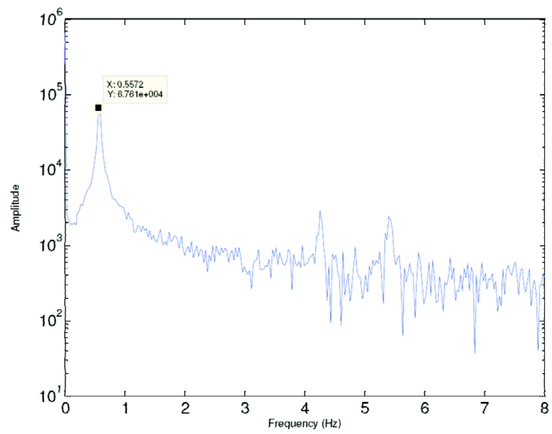

Figure 5: FFT for Cantilever Beam

It is observed from the test that a memory available for computation at the wireless mote is insufficient to perform FFT for 1024 number of data samples. With 128 data samples we have performed FFT at the remote microcontroller. Because of limited memory available on board. To establish a peer to per communication it needs still more memory which was already consumed in computation which limits to make use of these motes for per to per communication.

4. Conclusion

To investigate a suitability of low cost wireless sensor network elements in a SHM system, a laboratory test for a cantilever beam is carried out. In the test a local data obtained from the wireless module is used for FFT calculation. With the 128 sample of data FFT is carried at a remote wireless mote because of limited memory. For a SHM system of the structures e.g. mega wind turbine structures amount of data to be processed needs to be decided. It is planned to collect required amount of data from remote wireless module RF1 and send it to another remote wireless module RF2 and perform a correlation analysis at RF2. After computation at RF2 data will be send to the computer, in this way total amount of data handled and processed will be reduced. Further investigation of battery power requirement for data interrogation and data transmission can be obtained as extension to this ongoing work.

5. References

References

[1] Ciang, C.C, Lee, J-R. and Bang H.J., Structural health monitoring for a wind turbine system: a review of damage detection methods, IOP Publishing, Measurement science and technology. 19 (2008) 122001 (20pp).

[2] J.P.Lynch and Kenneth J. Loh, A summary review of wireless sensors and sensor network for structural health monitoring, The shock and Vibration Digest, Vol. 38, No. 2, (March 2006) 91-128.

[3] K. Worden, J.M. Dulieu-Barton, An overview of intelligent fault detection in systems and structures Structural Health Monitoring 2004 3 : 85.

[4] J.P.Lynch, A. Sundararajan, K.H. Low, A. S. Kiremidjian, Ed Carryer Embedding damage detection algorithms in a wireless sensing unit for operational power efficiency, Institute of Physics Publishing, Smart Materials and Structures 13 (2004) 800-810.

[5] R. Min, M. Bhardwaj, S.H.Cho, E. Shih, A. Sinha, A.Wang, A. Chandrakasan, Low-Power Wireless Sensor Networks, MIT,Cambridge.

[6] http://www.arduino.cc/en/Main/ArduinoBoardDuemilanove

[7] 8-bit AVR microcontroller product manual.

[8] XBee/XBee-PRO OEM RF module by MaxStream Inc., Product Manual v1.06.

[9] User's Guide for X-CTU Configuration and Test Utility Software.

[10] XBee Wireless Shield

[11] (+/-1.5g) three axis low-g, micromachined accelerometer, datasheet for MMA7361L, Rev 0, 04(2008).